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AIRCRAFT MODIFICATIONS COST ANALYSIS
VOLUME 1: OVERVIEW OF THE STUDY

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and
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February 1990

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As the budget for the development and production of new military aircraft tightens, modification of existing aircraft (MOD) has become increasingly important. This shift in emphiais emphasis has created a need for a high level parametric cost estimating method to estimate the cost of a MOD program early in the planning cycle. This report is the first volume of a series of reports documenting a multi-year project to support NAVAIR's initiative to develop parametric cost estimating models for MOD programs.

This volume provides an overview of the project, including a review of prior studies, the structure of data to be collected, and the forms used in data collection. Due to the proprietary nature of MOD program cost data, distribution of all future volumes of the report series except for the summary volume will be limited to selected Department of Defense agencies only.

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ABSTRACT

As the budget for the development and production of new military aircraft tightens, modification of existing aircraft (MOD) has become increasingly important. This shift in emphasis has created a need for a high level parametric cost estimating method to estimate the cost of a MOD program early in the planning cycle. This report is the first volume of a series of reports documenting a multi-year project to support NAVAIR's initiative to develop parametric cost estimation models for MOD programs.

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CHAPTER 1

OVERVIEW OF THE PROJECT

The size of the Federal deficit and the ever-increasing, high unit costs of new military aricraft have combined to alter the acquisition strategy of military aircraft. As the budget for the development and production of new military aircraft tightens, modification of existing aircraft has become increasingly important. For example, funds budgeted for **aircraft modifications** (**MOD**) for the Naval Air Systems Command (NAVAIR) approach two billion dollars annually. This shift in emphasis has created a need for a high level parametric cost estimating method to estimate the cost of a MOD program early in the planning cycle, when resource requirements must be budgeted before detailed knowledge of technical specifications is available.

PROJECT TASK ELEMENTS

This research was undertaken as a multi-year project to support NAVAIR's initiative to develop parametric cost estimation models for MOD programs. There are five major task elements required to accomplish this project:

Initial Survey of Data Availability and Structure

Modifications of military aircraft were performed either by **defense contractors** or **Naval Aviation Depots** (**NADEPs**). Therefore, both industry and NADEPs must be surveyed in order to ascertain the present state of MOD program data and the feasibility of using these data for the study.

Data Structure Formulation

Based upon the survey, a **cost element structure** will be formulated to ensure uniformity and consistency in data collection. This task is essential because cost terminologies and classification methods vary from one organization to the other. A sample of programs will be obtained and fit to the cost element structure. This will enable identification of potential physical, performance, and programmatic cost drivers.

Data Acquisition

Using the data structure formulated above, a data collection team will be organized to obtain cost, technical, and programmatic data from industry and NADEPs on selected MOD programs. Since the accounting data are not designed for cost estimating purpose, it is anticipated that the data collection team will have to extract relevant data from various sources on each site.

Data Development

The data obtained from the above task will be analyzed, normalized, documented, and placed on an electronic database for retrieval and subquent analysis. Relevant cost and program data from MOD programs will be included in separate volumes of this report series.

Development of Cost Estimating Methods

The database developed above will be the basis for developing **cost estimating relationships** for MOD programs. The procedures involved in data analysis and model development will be documented.

PHASE I TASKS

This report covers the tasks completed during FY88, including the literature research, the initial survey of data structures and availability, and the formulation of the structure for data collection and codification. Actual data acquisition began in the last quarter of FY88, the results of which will be reported in separate volumes.

Research Procedure

A survey of prior MOD cost estimating studies was conducted early in the study to ascertain the state of the art in this area. The results of literature research are summarized in Chapter 2 of this report.

An initial list of candidate MOD programs for possible inclusion in the study was developed by **NAVAIR Cost Analysis Division**. The respective contractor or NADEP was then contacted by one of the principal investigators to confirm their willingness to participate in the project and assess the suitability of the program for inclusion. Prospective contractors and NADEPs were visited by the principal investigators and/or a NAVAIR representative. Since the record keeping methods vary significantly from one contractor to another, the type of data and the level of detail needed for the project were explained to cognizant contractor personnel so that all might ascertain the availability of data and the appropriate way of extracting the needed data from the contractor's records.

The MOD **Work Breakdown Structure (WBS)** serves as the basis for data structure design. Based on the review of prior studies, the WBS, and initital visits to selected defense contractors, the data element structure was developed for the study, as discussed in Chapter 3. The WBS adapted for this study is shown in Appendix A.

A data acquisition team was then organized to collect data on-site. A separate volume of this report series will be devoted to each MOD program to describe the different organizational and accounting structures, the aircraft, the modifications performed on them, and the programmatic data collected. Cost data were collected to Level 3 (Level 4, if available) of the contract's WBS. Since each contract's WBS is different, adjustments were made to convert the data to the format shown in Appendix A. Due to the proprietary nature of MOD program cost data, distribution of all future volumes of the report series except for the summary volume will be limited to selected Department of Defense agencies only.

CHAPTER 2

REVIEW OF MOD PROGRAMS AND PRIOR STUDIES

This chapter reviews the reasons for aircraft modifications, discusses the significance of modification costs in the defense budget, and describes the need for a model to estimate modification costs in the planning process. The discussion will review past studies in the area of aircraft modification costs and describe the need within the Naval Air Systems Command (NAVAIR) for a cost model to be used in budget planning decisions.

REASONS FOR AIRCRAFT MODIFICATIONS

Organized military forces have always sought to upgrade and improve their weapons systems through modifications. Aircraft weapons systems have been no exception. Aircraft modifications are undertaken for four reasons.

Correct a Deficiency in the System

Deficiencies are typically discovered through operation of the aircraft during its service life. Deficiencies can be either of a safety or reliability nature. Safety deficiencies by their nature must be corrected quickly. A faulty ejection seat or a weak, failing structural member are examples of safety deficiencies. A reliability deficiency exists when a component of the weapons system does not function as was intended. For example, the installed air conditioning system may need to be replaced because it does not keep the cockpit avionics cool enough to operate properly. Deficiencies are normally corrected at the field level but can be done at the contractor or depot level.

Improve the Capability of the System

Rapid developments in technology have made some present-day weapons systems marginally effective for future use [Baker, Burgess, and Malkiewicz, 1973]. During the long time interval which encompasses an aircraft's design, procurement, and subsequent service life, advances in technology may render some of the aircraft subsystems, such as avionics, obsolete. Modification of the aircraft allows the operating forces to take advantage of advances in technology as they occur.

Extend the Service Life of the Aircraft

As weapons systems become more complex, the time interval required to design and procure a system becomes longer. Previous studies have shown that the acquisition cycle for new aircraft is increasing [Biery and Lorell, 1981]. As it takes longer for new aircraft to roll off the production line, so it becomes more important to maximize the life and usefulness of those already in service. This places greater importance on the use of modifications as an alternative to designing new systems. The service life of aircraft can be extended through structural modifications such as rewinging.

Reduce Downstream Operating/Maintenance Costs

Downstream maintenance costs may be reduced by replacing components with others which require fewer maintenance hours. Newer avionics or engines which require fewer man-hours of maintenance per hour of flight time are examples. Operating costs can be reduced by replacement or installation of components which reduce the number of operational failures. This would result in fewer aborted missions and increased operational readiness. Operating costs may also be reduced by installation of components which are more efficient, such as a fuel efficient engine.

MODIFICATION IN LIEU OF PROCUREMENT

The need to improve the capability and to extend the service life of weapons systems has led to a concept in weapons procurement known as ***Modification in Lieu of Procurement***. Modification in lieu of procurement simply means to extend the useful life of existing weapons systems rather than to develop and procure new weapons systems. The modification in lieu of procurement concept has received greater attention in the last decade because of increasing weapons system costs and tighter military procurement budgets. The importance of modification in lieu of procurement to aircraft programs was underscored by Vice Admiral Wesley L. McDonald, Deputy Chief of Naval Operations for Air Warfare:

> Within the limited resources provided to the USN, the only way to maintain the current posture of air defense was to procure new aircraft and to modify those in the inventory to the 'state of the art.' By modifying and modernizing existing weapons systems, a significant overall cost savings can be generated. [Mitchell, p. 13]

Modification of existing aircraft in lieu of developing new ones has been used successfully for several programs in the past. The A-7 Corsair, F-4 Phantom, and B-52

Stratofortress are three examples of aircraft whose useful service lives have been extended considerably through modifications.

As the use of modifications has increased, the costs associated with them have grown to occupy an increasingly significant portion of the total defense budget.

THE NEED FOR MODIFICATION COST MODELS

Weapons system modifications consume a large portion of defense funds. For example, the U.S. Navy currently spends close to $2 billion annually on aircraft modifications. The study by Baker, Burgess, and Malkiewicz found that:

> Weapon system modification costs accumulate to form a significant portion of the overall inventory investment cost, which is clearly demonstrated by a brief examination of the B-52 weapon system. The original acquisition cost for 744 B-52 aircraft was $6951.3 million. From 1955 through 1965, modification costs on the aircraft totaled $1707.2 million, which represents 24.5 percent of the acquisition cost. Since 1965, modification costs on the B-52 have continued to increase, especially because of their increased use and activity in the Vietnam War. These cost figures emphasize the importance and dollar value of modification programs. [1973, p. 3]

Given the dollar value of aircraft modifications and their increased use, a method for predicting their cost early in the planning process is necessary.

Each military service has a formal structure for initiating, reviewing, and approving modifications to existing weapons systems. The modifications typically require approval at the highest level within each service's system program office.

A service's decision to make a modification involves a tradeoff between its cost and the capability it adds to the weapons system. Consideration must also be given to the downstream savings in operation and maintenance costs. Procuring a new system as opposed to modifying an existing one will involve higher research and development costs. A parametric model is needed because the costs associated with each alternative must be estimated before detailed information is known or available.

Once approved, modifications must be incorporated into the Department of Defense Planning, Programming, and Budgeting System in order to seek funding approval. Because of budgetary constraints, all programs must be reviewed carefully against their alternatives.

In order to make decisions in the process just described, decision makers must be able to estimate modification costs early in the planning process. Although modification costs can be estimated in great detail once specific knowledge of the modification is obtained, the procedure is time consuming and detailed knowledge may not be available early enough in the process to be useful for program planning. A simple model is all that is needed to conduct planning studies, preliminary tradeoff analyses, and cost analyses. In spite of the need for one, no comprehensive model for predicting aircraft modification costs has yet been developed.

Presently, NAVAIR has no model for estimating the cost of aircraft modifications. A 1983 audit of the DoD Aircraft Modification Program by the Office of the Inspector General, Department of Defense, pointed out the need for adequate planning of modifications:

> Modifications will continue to consume a large share of defense funds and man-hours. The quantity and cost of proposed modifications at any given time greatly exceeds the amount of funds available to the Military Departments. For this reason, it is important that each modification proposal be adequately planned, thoroughly justified and professionally managed. [Office of the Inspector General, 1983]

Secretary of the Navy Instruction 7000.14 (series) requires that parametric cost estimates be made at key decision points for major weapons systems. In particular, they are required during concept formulation, before making major commitments of funds for development and production.

PREVIOUS STUDIES IN MODIFICATIONS COST MODELING

The RAND Corporation has done much of the existing research in the area of estimating costs of aircraft modifications. A 1978 RAND study undertaken for the U.S. Air Force evaluated whether several existing **Life Cycle Cost** (**LCC**) models were effective in determining costs of major modifications to aircraft [Marks, Massey, and Bradley, 1978]. There are a wide variety of LCC models for aircraft systems used by the military services and commercial manufacturers. The specific models evaluated were:

- Budgeting Annual Cost Estimating (BACE) model.
- Cost Analysis Cost Estimating (CACE) model.
- Logistics Support Cost (LSC) model.
- Logistics Composite Model (LCOM).
- MOD-METRIC.
- AFM 26-3 Manpower Standards.
- Air Force Logistics Command Cost Equations.
- Programmed Review of Information for Costing and Evaluation (PRICE).
- Development and Production Costs of Aircraft (DAPCA).

The first seven are Air Force models, **PRICE** is a model developed by RCA for avionics development and procurement costs, and DAPCA was developed by the RAND Corporation. The study concluded that those LCC models reviewed have many shortcomings and are of limited use, particularly for evaluating the cost of major aircraft modifications.

In 1981, the Air Force contracted RAND to develop parametric cost estimating methods for predicting the costs of aircraft structural modifications [Birkler and Large, 1981]. The study used cost data from the aircraft industry to develop a series of parametric equations for estimating modification costs of airframe systems and subassemblies. When the equations were tested against the actual costs of four modification programs, the report concluded that the model, taken by itself, did not provide reliable estimates of aircraft modification costs. However, the equations were found to be useful in cost estimation if they were used with discretion and understanding. Particularly, knowledge of the aircraft's prior production history was identified as a necessary element. For example, if the tooling from the original production program was in storage and available for use, it could significantly affect the cost of a modification. By using the original production tooling, the contractor would not have to design and fabricate new tooling for the modification.

There were other studies on aircraft modification costs which focused on managing the costs after the program has been approved rather than cost estimation. Mitchell [1981] reviewed the fiscal management of aircraft modification funds within the Navy. His study focused on the problems associated with control and expenditure of appropriated funds for aircraft modifications. The study noted areas for improvement in the management of funds, but its scope was centered in the budget execution area and it did not address the problem of estimating modification costs in the planning stage.

The study by Baker, Burgess, and Malkiewicz [1973] examined cost factors and budget aspects of Air Force Class IV aircraft modifications. Class IV modifications are required to insure safety of personnel, correct equipment deficiencies, or improve logistic support capabilities. Based on input from the engineers and technicians, the study determined cost factors which should be included on Air Force budget submission forms. The forms examined in the study were detailed engineering estimates used in the budgeting process, after modifications have been approved and when costs can be estimated with much detail. They require much more detail than would be available in the preliminary planning of the modifications.

OBSTACLES IN THE DEVELOPMENT OF A COST MODEL

Developing a reliable model to predict aircraft modification costs is a difficult task. There are several factors which hinder the development of an aircraft modification cost model.

1. *Modifications Vary in Complexity*

Aircraft modifications vary greatly in complexity. A modification may involve rewinging, re-engining, upgrading of avionics, stretching the fuselage, conversion of the aircraft to perform a different mission, or any of a number of other items. No two aircraft modifications involve exactly the same conversions.

2. *Modifications Vary by Individual Aircraft*

Modifications normally involve a series of aircraft with the same model designation. No two aircraft in the series may have the same configuration because of alterations and backfitting while they are in the fleet. The alterations may not be completed on all of the aircraft at the time they go through modification. Also, physical conditions of each aircraft will differ because they have been operated under different conditions or environments. An aircraft operated from an aircraft carrier will show more structural fatigue and corrosion than one operated from land. Some of the aircraft will have received damage, such as battle damage, which will make them unique. These conditions make it difficult to develop a single, simple cost model to predict the modification costs.

3. *Modifications Vary in Methods and Organizations*

The complexity of the modification and the variety of ways in which installations are accomplished contribute to the differences in time required to complete them. Normally, the materials and components are assembled into kits. The kits are then installed in the aircraft either at the organizational, intermediate, or depot level. Work on aircraft modifications can be performed by civilian contractors, Naval Aviation Depots (NADEPs), or organizational level units or any combination of the three.

4. *Modifications Vary in Prior Experience and Facilities*

Birkler and Large's study [1981] concluded that detailed knowledge of the original production program and the proposed modification is essential in estimating costs. Modification is easier for the original producer of the aircraft due to knowledge of the original design and specification and, in some cases, the availability of tools from the production program.

CHAPTER 3

DATA STRUCTURE

This chapter identifies variables which are to be considered in the development of the modification cost model and describe the methods used for collecting data and building a database. The variables will be described as either costs/manhours, or potential cost drivers depending on whether they are dependent or independent variables, respectively, in a model. The discussion of data collection will include an explanation of Work Breakdown Structures (WBS) as well as the Contractor Cost Data Reporting (CCDR) system and how they relate to the data collection effort.

COST DATA AND POTENTIAL COST DRIVERS

The dependent variable for the parametric cost estimating models will be cost data in the form of dollar costs or manhours required to complete aircraft modification tasks. The costs and manhours necessary for planned modifications are unknown variables. They must be estimated from some known parametric descriptors (cost drivers). This section discusses the cost data and potential cost drivers collected in this study.

Cost Data Collected

Dollar costs and manhours for aircraft modifications are collected in four major categories:

- Direct Labor Hours by functional area.
- Material Dollars.
- Subcontract Dollars.
- Total Cost including General and Administrative expense.

A. Direct Labor Hours

Direct labor hours identify the direct costs of labor which went into the modification. They are segregated by functional category and are used as surrogates for the dollar cost of labor. Using direct labor hours has the advantages of eliminating the effects of inflation and nullifying differences in labor rates among different companies. Isolation of manhours into functional areas allows for development of a more detailed and reliable parametric model. Direct labor hours are collected in the functional categories of Engineering, Tooling, Manufacturing, and Quality Control with further segregation within each of those categories.

(1) **Engineering Hours**: Engineering hours refer to the contractor's engineering efforts for design, development, and integration of the modification. Engineering hours are further segregated into the categories of Design, Test, or Other. Engineering efforts expended under tooling and production planning are collected under the cost element of Tooling Hours.

(2) **Tooling Hours**: Tooling includes assembly tools, dies, jigs, fixtures, work platforms, and test and checkout equipment. Tooling hours include all efforts expended in tool and production planning, design, fabrication, assembly, installation, and maintenance. Tooling Hours are further classified into subcategories of Design,

Fabrication, and Planning.

(3) **Manufacturing Hours**: Manufacturing hours include all direct labor used to machine, process, fabricate, assemble, and install the components involved in the modification. Manufacturing hours are identified as either Fabrication or Assembly.

(4) **Quality Control Hours**: Efforts spent to ensure that prescribed specifications and standards are met comprise Quality Control. It includes receiving inspections; in-process and final inspections of tools, parts, and assemblies; and reliability testing and failure review. Quality Control hours are further separated as either Tooling or Manufacturing.

B. Material Dollars

This cost category will identify all direct costs of materials and equipment necessary to complete the modification. Material costs are segregated into Raw Material/ Purchased Parts, Purchased Equipment, Purchased Tooling, and Purchased Test Equipment. Separation of material costs into these categories allows for better detail in constructing the cost model.

C. Subcontract Dollars

This cost category is necessary in order to identify the efforts and costs of subcontractors used in the modification. The amount of subcontracting varies greatly with different aircraft modifications. Different manufacturers treat subcontractor costs differently. Some convert subcontract costs into hours and material costs and add them to in-house labor and materials. Others assign all subcontract costs as material costs. In order to build a valid parametric model, it is necessary to identify the subcontractor costs and how they were treated to insure that they are comparable across different programs.

D. Total Cost

The final cost category is the total cost of modification, including general and administrative expenses. This category includes the efforts associated with the previous three cost categories. However, it excludes profit, royalties, and the cost of money, which are not directly attributable to the modification and are normally excluded in cost estimation models of this type.

All costs and manhours are further identified as either recurring or nonrecurring. ***Recurring*** efforts are incurred for every aircraft which is modified, and include items such as raw materials, tool maintenance, and acceptance testing. ***Nonrecurring*** efforts are incurred only once and are not a function of how many aircraft are modified. Initial tooling, wind tunnel models, and developmental testing are examples of nonrecurring efforts. It is important to distinguish between recurring and nonrecurring cost data since they are sensitive to different cost drivers.

Cost data are collected onto Functional Cost History sheets in the format illustrated in Appendix B.

Potential Cost Drivers Collected

The potential cost drivers which may be relevant depend greatly upon the specifics of the modification program. For example, **weight added** or **removed** is a logical variable for any structural modification done to the aircraft. Weight is an indicator of size. Therefore, a large structural modification should cost more than a small one. Weight data are collected by calculating the weight added, removed, and modified for each subsystem or structural subassembly. Avionics, armament, and flight controls are examples of subsystems while the wing, tail, and nacelle are examples of structural subassemblies. Collecting weight data in this manner is necessary because of the diverse nature of modifications. It allows the various tasks involved in different modifications to be isolated so that modifications with similar tasks can be made comparable.

For avionics modifications, the weight added may be considered as a relevant cost driver. Also, the number of major cable runs, or the number of equipment racks, antennas, and "black boxes" added could all be good predictors of cost. An increase in any of those attributes would indicate an increase in cost.

The number of test aircraft, number of test flights, flight months, and flight hours might be used as cost drivers for system development and flight test costs. Here again, an increase in the test flight attributes would logically result in increased costs.

The availability of cost driver variables depends upon what was done for each modification and what programmatic data are available from the contractor. Appendix C provides a worksheet for collecting the programmatic and cost driver data.

The breakdown of costs and manhours by functional area discussed earlier provides for building a more accurate model. However, a further breakdown of cost data, which will be discussed next, is still necessary.

WORK BREAKDOWN STRUCTURE VS. FUNCTIONAL COSTS

In order to properly construct a model, data must be broken down according to the varying degrees of effort put into vastly different aircraft modifications. Isolation of the efforts which went into different areas of a modification is necessary in order to make the data between two programs comparable. For example, assume two manufacturers performed very similar modifications: one program involved fabrication and installation of the airframe kit, while the other required only fabrication of the kit. The kit installation costs of the first manufacturer must be isolated and removed in order for the data to be comparable between the two.

For that reason, the data in this study are collected by **functional costs and manhours** for each level in a **Work Breakdown Structure**. Military Standard 881A defines WBSs for Defense Materiel Items and establishes criteria for when they should be used. A WBS is a product-oriented family tree composed of hardware, services, and data which result from project engineering efforts during the development and production of a defense materiel item, and which completely defines the project/program. A WBS displays and defines the product(s) to be developed or produced, and relates the elements of work to be accomplished to each other and to the end product. A WBS is organized into levels, with project elements becoming more disaggregated as the levels increase. For example, Level One in a typical WBS refers to the program as a whole, while a Level Four element refers to a specific subset of that program, such as wind tunnel testing. Appendix A provides the model WBS for which MOD data are collected in this study. Additionally, the **Contractor Cost Data Reporting** system, to be discussed next, requires that data be collected in WBS format for many government contracts.

CONTRACTOR COST DATA REPORTING (CCDR) SYSTEM

In 1970 the Department of Defense (DOD) recognized the need for a common database for use in preparing reliable, parametric cost estimates [NAVMAT, 1973]. The Contractor Cost Data Reporting system was established in November 1973 in order to develop a common database. The CCDR system is designed to assist all DOD components in the following:

- Preparing cost estimates for major system acquisitions.
- Developing independent cost estimates in support of cost/price analyses and contract negotiations.
- Tracking contractors' negotiated costs.

The CCDR system provides uniform procedures to defense contractors for collecting and reporting costs. The system mandates that contracts exceeding certain dollar limits require the contractor to collect and report data in WBS format. The WBS for the contract is established by the Contracting Officer in the Request for Proposal (RFP). The reports required by the CCDR system are the primary basis for collection of data in this study.

COLLECTION OF DATA

In order to establish a sufficient database, data are collected from modification programs performed on many aircraft of the different U.S. military services, as well as some modified for foreign military sales. Data are collected for programs as far back as possible. For these reasons, not all data are available in WBS format. If a WBS does not exist, the researchers establish a WBS and attempt to place the data in that format.

Two additional remarks should be made to facilitate data interpretation. The first is the fact that manufacturers have different accounting systems and do not collect costs in the same manner. This is because civilian manufacturers have considerable flexibility in classifying costs, such as recurring and nonrecurring. Second, WBS requirements are not uniform across all contracts. In these cases, knowledge of the individual program and the contractor involved are used to interpret the data into the format developed for this project.

REFERENCES

Baker, E.M., Burgess, W.H. and Malkiewicz, A.F., An Investigation of Cost Factors Relating to Class IV Aircraft Modifications, Master's Thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1973.

Biery, F. and Lorell, M., Preplanned Product Improvement and Other Modification Strategies: Lessons from Past Aircraft Modification Programs, The RAND Corporation, Santa Monica, California, 1981.

Birkler, J.L., and Large, J.P., A Method for Estimating the Cost of Aircraft Structural Modification, The RAND Corporation, Santa Monica, California, 1981.

General Accounting Office, Report by the Comptroller General of the United States, C-5A Wing Modification: A Case Study Illustrating Problems in the Defense Acquisition Process, U.S. General Accounting Office, Gaithersburg, Maryland, 22 March 1982.

Mitchell, L.C., An Analytical Review of the Management of Modification Funds in the Naval Aviation Community, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1981.

Marks, K.E., Massey, H.G., and Bradley, B.D., An Appraisal of Models Used in Life Cycle Cost Estimation for USAF Aircraft Systems, The RAND Corporation, Santa Monica, California, 1978.

Budget of the United States Government, FY 1988, Appendix, Government Printing Office, Washington, D.C., 1987.

Office of the Inspector General, Department of Defense, Audit Report, DoD Aircraft Modification Program, Government Printing Office, Washington, D.C., 1983.

Department of Defense Military Standard 881A, Work Breakdown Structures, 25 April 1975.

Naval Material Command NAVMAT P-5241, Contractor Cost Data Reporting System, 5 November 1973.

APPENDIX A

AIRCRAFT MODIFICATIONS (MOD) WORK BREAKDOWN STRUCTURE

Level 1	2	3	4	
0000				Modification Project
	1000			Air Vehicle
		1100		Airframe Kit
			1110	Wings/Rotor
			1120	Fuselage
			1130	Empennage
			1140	Nacelles
			1150	Landing Gear
			1160	Electrical Subsystem
			1170	Environmental Control Subsystem
			1180	Secondary Power System
			1190	Flight Control System
			11A0	Crew Station Subsystems
			11B0	Hydraulic/Pneumatic Subsystems
			11C0	Ancillary Propulsion Equipment
			11D0	Installation Structures
			11E0	Kit Packaging, Hdlg. & Transp.
		1200		Air Vehicle Integration, Installation, Checkout
		1300		Propulsion
		1400		Avionics Systems Integration
		1500		Air Vehicle Application Software
		1600		Air Vehicle System Software
		1700		Avionics
		1800		Auxilliary Equipment
		1900		Over & Above
		1A00		Other Air Vehicle
	2000			System Test & Evaluation (ST&E)
		2100		Development Test and Evaluation
			2110	Contractor Flight Test
			2120	Avionics Integration Testing
			2130	Wind Tunnel Test Program
			2140	Air Vehicle Subsystem Test
			2150	Mockups
			2160	Other Developmental Test & Eval.
		2200		Operational Test & Evaluation (OT&E)
		2300		Test and Evaluation (T&E) Support
		2400		Test Facilities
		2500		Other Systems Test and Evaluation
	3000			System Engineering/Program Management
		3100		System Engineering (Non-ILS)
		3200		Program Management (Non-ILS)
		3300		System Engineering (ILS)
		3400		Program Management (ILS)
	4000			Data
		4100		Non-ILS Data
		4200		ILS Data
	5000			Training
		5100		Training Equipment
		5200		Training Services
		5300		Training Facilities
	6000			Common Support Equipment
	7000			Peculiar Support Equipment
	8000			Interim Spares & Repair Parts
	9000			Operational/Site Activation

APPENDIX B

FUNCTIONAL COST HISTORY

PROGRAM
LOT/FY:
WBS:

COMPANY:
CONTRACT:
QTY:

FUNCTIONAL COST CATEGORY	PRIME	STRUCTURAL SUB CONTRACTOR	TOTAL	PRIME	STRUCTURAL SUB CONTRACTOR	TOTAL	PRIME	STRUCTURAL SUB CONTRACTOR	TOTAL
ENGINEERING HOURS									
DESIGN									
TEST									
OTHER									
TOOLING HOURS									
DESIGN									
FABRICATION									
PLANNING									
MANUFACTURING HOURS									
FABRICATION									
METAL (CONVENTIONAL)									
COMPOSITES									
ASSEMBLY									
AIRFRAME & SUBSYSTEMS									
PC BOARDS									
QUALITY CONTROL HOURS									
TOOLING QC HOURS									
MANUFACTURING QC HOURS									
MATERIAL DOLLARS									
RAW MATERIAL/PURCHASED PARTS									
PURCHASED EQUIPMENT									
PURCHASED TOOLING									
PURCHASED TEST EQUIPMENT									
SUBCONTRACT DOLLARS									
TOTAL COST + G&A									
		RECURRING			NONRECURRING			TOTAL	

NOTES:

APPENDIX C

NAVY PG SCHOOL/NAVAIR MODIFICATION COST PROJECT ESTIMATING PARAMETERS FORM

Name of Aircraft: ____________________

Name of Modification Program: ____________________

Contractor: ____________________

Navy Investigator: ____________________

Contacts and Phone Numbers: ____________________

PROGRAMMATIC INFORMATION

1. Contract(s) Type and Number (all contracts funding mod):
2. Number of Aircraft: ____________________
3. Schedule:

    Initial Program Go-Ahead: ____________________

    Critical Design Review: ____________________

    Flight Test (span): ____________________

    Period of Performance (span): ____________________

4. A/C Type: ____________________

    (Fighter, Attack, Bomber, ASW, Cargo, Tanker, Helicopter)

5. Kit Fabricator Facility Location: ____________________
6. Kit Installation Facility Location: ____________________

PROGRAM HISTORY

a. Description of Program:

b. Description of Data Requirements (include document count and tech pubs page count):

c. Description of Training Program:

d. Description of Support Equipment Requirements:

e. Description of Operational and Site Activation Support:

f. Description of Spares Requirements:

g. Description of Tooling (include breakout of hard and soft tooling, prototype tooling, and any composite tooling):

h. Description of Mockups (indicate Class I, II, III):

i. Description of Large Problems (rework, late GFE, configuration changes, etc.):

j. Description of programmatic changes (changes in CFE/GFE mix over time, accounting changes like direct vs. indirect changes over time, ratio of contracted effort for Over and Above over time):

k. Description of quality of modification candidates (Were candidates picked by Service Operational levels or higher level? Who performed the last overhaul and when was it done? Were the aircraft used for training or battle damaged? What is the past history of this class of aircraft?):

1. Description of requirements for removed parts (Were they disposed of, repaired, cleaned, or sent to service repair facility?):

TECHNICAL INFORMATION

1. Modification Hardware Weights

	Installed		Removed	Modified	
	Inplant	Procured		Inplant	Procured
Total Structure					
Rotor					
Wing					
Tail					
Body					
Alighting Gear					
Surface Controls					
Engine Section/ Nacelles					
Propulsion					
Total Equipment					
Auxiliary Power Plant					
Flight Controls					
Instruments					
Hydraulics and Pneumatics					
Electrical					
Avionics					
Equipment					
Installation					
Armament					
Furnishings and Equipment					
Air-Cond. and Anti-Icing					
Photographic					
Auxiliary Gear					
	--------	-------	--------	--------	-------
Total Hardware Weight					

2. Aircraft Weights

	Prior to Modification	Following Modification
Airframe Unit Weight:	________	________
Weight Empty:	________	________
Structure Weight:	________	________
Electrical Group Weight:	________	________

3. Dimensional and Structural Data

	Length	Depth	Width	Surface Area (wet area)	Volume	Volume Pressurized
Fuselage	____	____	____	_______	____	________

4. Test and Evaluation

No. of Flights: ______________________________

No. of Flight Months: ________________________

No. of Flight Hours: _________________________

No. of Airworthiness Flight Hours: ______________

No. of Data Channels: _______________________

5. Avionics

I. Hardware | Installed | Removed | Modified

A. Physical Attributes
1. Dimensions/Volume
2. Weight
3. # of WRA's (Black Boxes)
4. # of Racks
5. # of Antennas
6. # of Major Cable Runs

B. System Use
1. Commodity Functional Area(s)
2. Operating Environments
a. Input/Output Power ________________
b. Method of Power Generation ___________
c. Method of Cooling _________________

II. Software

A. Deliverable Lines of Source Code (Instructions Only)
____

B. Language Used __________________________

C. Utilization of Planned Memory Capacity (%) _____

D. Placement
1. Detached _____________
2. Semi-Detached __________
3. Embedded _____________

NAVAIR POINTS OF CONTACT

Avionics: Chuck Taylor (NAVAIR 52413) 202-692-7688
Other: Mike Biver (NAVAIR 5241) 202-692-7738/9

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